Quantitative evaluation of the national road network around Ishikawa Prefecture based on the number of non-intersecting routes.

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Many of the infrastructure systems in modern society can be represented by simple networks of points and edges. However, these networks are becoming larger and more complex, and the consequences of damage are likely to increase. Road networks, one of the most important infrastructures in modern society, are no exception. The severance of infrastructure due to earthquakes, snow damage, etc. has had a major impact on logistics. However, if alternative routes can be constructed to avoid the damaged parts of the network when it is damaged, the network can be resilient to failure. To facilitate the construction of alternative routes, the number of routes in the network that do not share points or edges with each other, i.e. non-intersecting routes, is important.

In this study, the number of non-intersecting routes is calculated for the national highway network from Ishikawa Prefecture to Osaka, Aichi and Tokyo, which are the representative points of Kansai, Chubu and Kanto, the central cities of logistics. However, it is known that the computational complexity of the problem of finding the number of non-intersecting routes is enormous, since each side of the national road network has a possible bi-directional path. Therefore, in this study, the target network is mapped onto a planar, unclosed, finite and directed graph, and the number of non-intersecting routes is obtained in an approximate way by applying the properties of the path sum matrix, a mathematical physics method. In this study, the national road network was mapped using a geographical information system based on road data distributed by the Ministry of Land, Infrastructure, Transport and Tourism. The mapping is directed so that the vectors of start/end points on the network are oriented so that the inner product with the edges is greater than zero, so that there are no closed roads and no detours are allowed. By using the algorithm of token propagation on the mapped data, the number of paths of the target start and end points is efficiently obtained and a path union matrix is created. The algorithm of token propagation takes a certain point as a starting point and passes tokens to neighbouring points. The value of the token at each point is equal to the number of times it is passed, i.e. the number of times it is passed, so the path sum can be obtained in an unclosed, finite and directed network. The analysis shows that there are several localities where the number of non-intersecting routes becomes zero when one major national road becomes unavailable. For example, when National Highway No. 8 is disabled,

there is only one route in Fukui and Shiga Prefectures, and the number of non-intersecting routes from Ishikawa to Osaka is zero. If Route 158 is not available, there will be no east-west route between Gifu and Nagano, and the number of non-intersecting routes from Ishikawa to Tokyo will be zero.

The national road network to Ishikawa Prefecture is found to be heavily dependent on two national roads. National Highway No. 8 and No. 158 are well-known for their heavy snow damage. It is considered that the unavailability of major national roads in the event of a disaster would have a significant impact, and it is therefore clear that new routes need to be constructed to avoid damage to logistics.